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NOTE ON EFFECTS OF MASS ADDITION ON THE STABILITY OF SLENDER CONES AT HYPERSONIC SPEEDS

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The effect of mass addition on the flow over bodies moving at hypersonic speeds has been studied by several investigators (see, e.g., ref. 1). In most of this work primary attention has logically been directed toward the effects of foreign gas injection on heat transfer and pressure distributions, and principally for this reason, most of the work has been done at zero angle of attack. The foreign gas can be provided either by some active injection system or by the action of an ablation heat shield. With increasing rates of injection the basic flow about the body can be affected significantly. One such effect was observed in reference 1, where it was shown that the shock-wave standoff distance can be increased by gas injection at the nose of a body.

Another effect of mass addition at the nose has been investigated in the 14-Inch Helium Tunnel at the NASA Ames Research Center. In this study, a cone having a semi-vertex angle of 10° was tested at a Mach number of 21 and at a Reynolds number (based on length) of 4.5 million. The cone was 2 inches in diameter at the base and had a hemispherical tip of 0.076 inch radius. In this hemispherical tip were one hole 0.040 inch diameter and

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eight holes 0.025 inch in diameter. From these holes helium was injected at various rates and the effects of this gas injection on forces and moments were determined at angles of attack up to about 14°.

Some of the results of this investigation are shown in Fig. 1. For these results, the mass rate parameter, $\dot{m}$, is the ratio of the mass rate of injection to the product of the free-stream velocity, free-stream density, and body base area. These results show that the mass addition decreases the stability at low angles of attack and increases it at intermediate angles. In fact, a crossover occurs and at higher angles the pitching moments are increased in magnitude compared to those for the body without injection. With increasing mass addition, the changes in stability and moments become more pronounced and the crossover angle of attack increases. The normal force, however, decreases with increasing injection rate at all angles of attack, although the reductions are somewhat less at the higher angles. A possible explanation for this behavior can be obtained with the aid of the results of another series of tests. The same cone with a series of oversized spheres at the tip was tested at a Mach number of 18 and a Reynolds number of 3.7 million. The direct contribution of the sphere drag on the normal forces and pitching moments was assumed to correspond to a drag coefficient of 1.0; this contribution was subtracted to obtain the results shown in Fig. 2. Note that increasing sphere size has the same effect on pitching moments and normal forces as increasing mass addition rate.

From these latter results, it is suggested that "separationlike" phenomena may be occurring as follows: The injection creates a relatively thick layer of low-energy gas which nearly encases the cone. In many respects this layer behaves as a separated region. When the cone is inclined, the layer cannot readily support the circumferential variation of pressure which produces normal loading. For this reason, both normal force and pitching moment would be reduced at least at small angles of attack where the cone remains nearly encased in the separated layer. At somewhat higher angles, the separated or low-energy gas will collect on the lee side of the cone. Accordingly, the extent of separation on the windward side will be reduced and in unseparated regions increased normal loading will be possible. Obviously this trend will occur at lower angles when the separated layer is thinner relative to the body radius. For the test cones, considerations of geometry and continuity indicate that the separated layer is indeed thinner relative to the radius toward the rear of the body. From these considerations, it appears that the loading should return to the portions of the body aft of the moment center at lower angles of attack then it returns to the portions forward of the moment center. For this reason, it is suggested that at some intermediate angles of attack the moments for a body with separation may exceed in magnitude those for a body without. At these angles, however, the normal forces will still be reduced compared to those for a body without separation. These trends are, of course, those observed in the experimental results.

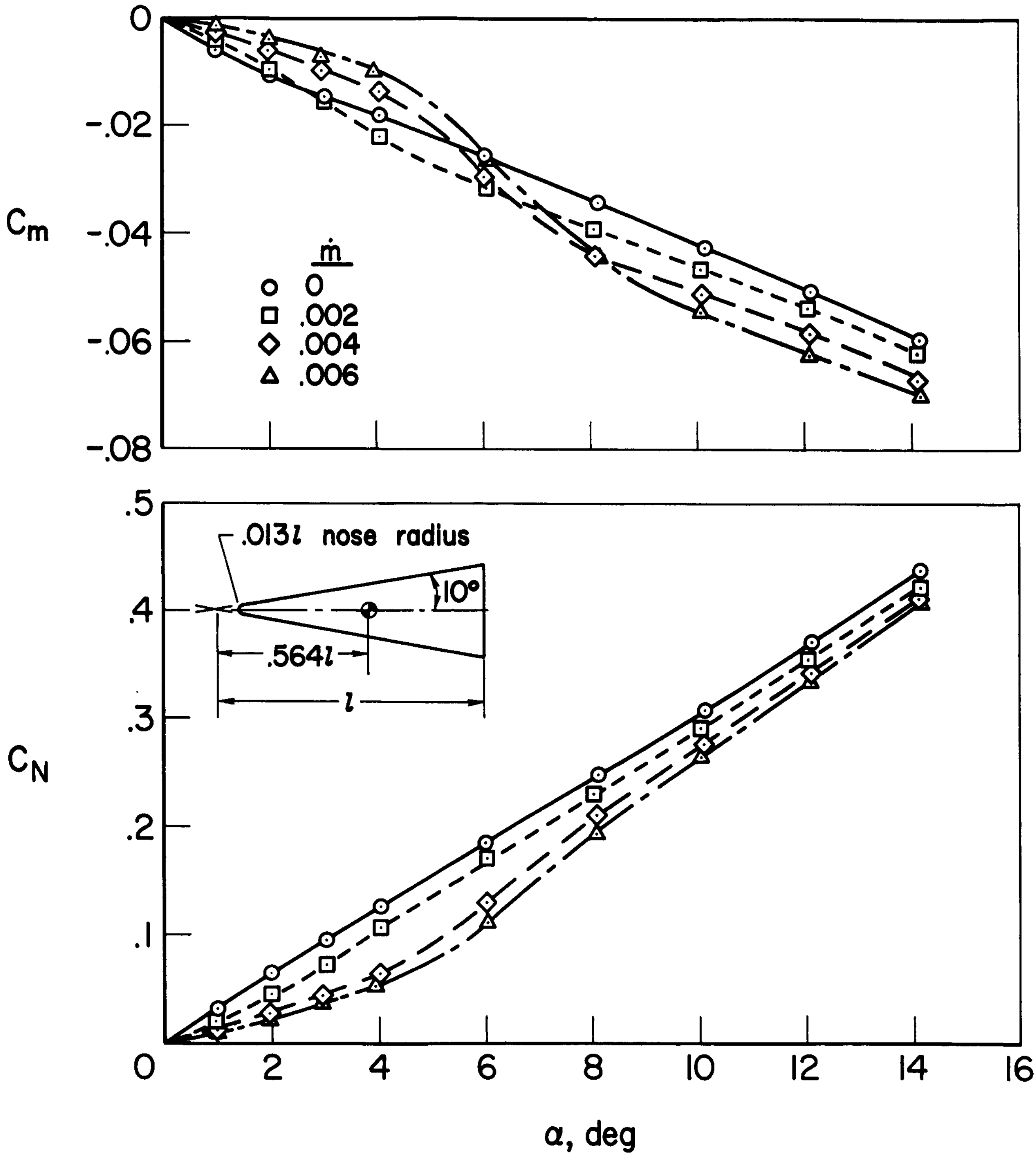
REFERENCE

1. Cresci, Robert J., and Libby, Paul A.: The Downstream Influence of Mass Transfer at the Nose of a Slender Cone. Jour. Aerospace Sci., vol. 29, no. 7, July 1962, pp. 815-826.

FIGURE LEGENDS

Fig. 1.- Effect of mass addition on the normal-force and pitching-moment coefficients for a cone at a Mach number of 21.1 in helium.

Fig. 2.- Effect of oversized spherical bluntness on pitching-moments and normal-force coefficients for a cone at $M = 18.1$ in helium.



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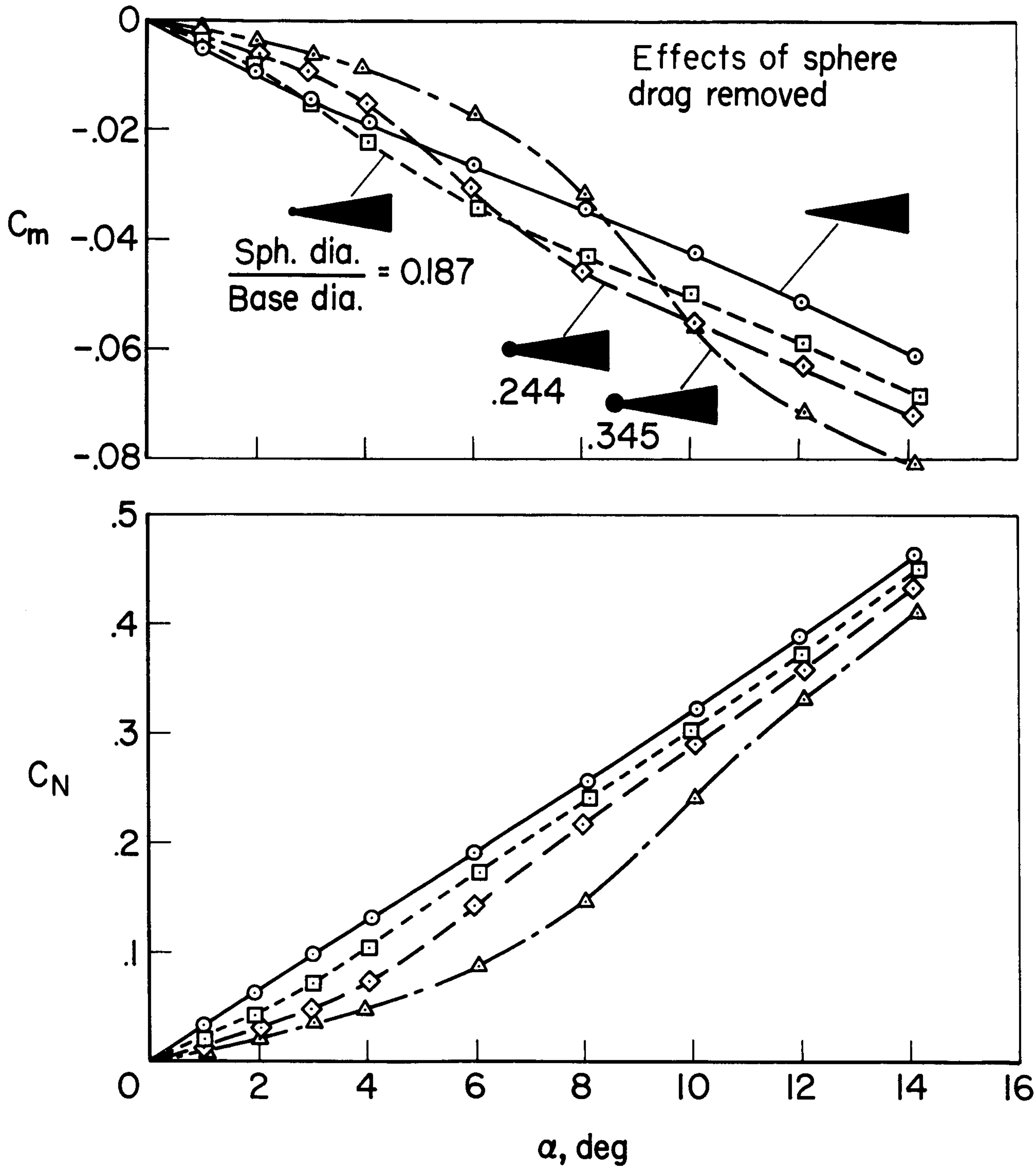

Fig. 2.- Effect of oversized spherical bluntness on pitching-moments and normal-force coefficients for a cone at M = 18.1 in helium.